Unconscious priming of task sets: The role of spatial attention

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Abstract Unconscious stimuli activate *task sets*, mental programs that orchestrate performance of complex tasks, but the role of attention in such effects has not been addressed. In previous studies, unconscious prime stimuli appeared at attended locations and were explicitly specified in the task instructions; spatial attention to the prime and/or a specific conscious *attentional set* may thus be required for such unconscious activation to arise. In the present experiments, a learning phase established associations between unconscious prime stimuli and performance of two tasks. These associations influenced task performance in a subsequent test phase, even though the primes were not specified in current task instructions. This is the first demonstration that unconscious stimuli can prime task sets independently of a current attentional set that specifies stimulus–task mappings. Such priming was not influenced by spatial attention cues, in contrast to clear attention influences in comparison trials that mimicked conditions employed by previous studies.

Keywords Unconscious perception · Priming · Cognitive control · Attention · Executive · Dorsolateral prefrontal cortex · dlPFC

Introduction

Perceptual, semantic, and motor functions can all be influenced by stimuli that fail to meet objectively defined

thresholds for conscious perception (Cheesman & Merikle, 1986; Dehaene et al., 1998; Enns & Di Lollo, 2004; Klapp, 2007; Klotz & Neumann, 1999; Kouider & Dehaene, 2007; Mattler, 2003, 2005; Sumner, Tsai, Yu, & Nachev, 2006), including very high level processes (Dijksterhuis, Bos, Nordgren, & van Baaren, 2006; Ferguson & Bargh, 2004). In contrast, executive processes of cognitive control, which operate to prevent reflexive processing from dominating cognition and action and to guide rule-based responses to stimuli, have been widely assumed to require conscious attention (Baars, 1989; Dehaene & Naccache, 2001; Jack & Shallice, 2001; Norman & Shallice, 1986). This apparent exclusive preserve of conscious processing has shaped influential theories about likely functions of consciousness in both cognitive science and philosophy. However, three recent studies have claimed that executive functions can be triggered unconsciously, in apparent contradiction of these views.

Lau and Passingham (2007) examined the effects of unconsciously perceived stimuli on participants' preparation to perform one of two word tasks (semantic or phonological). Under such conditions, executive processes select the requisite mental programs, or *task sets*, to perform one task and inhibit responses associated with another (DiGirolamo et al., 2001; Wylie, Javitt, & Foxe, 2006). On each trial of their study, a conscious task instruction (a diamond or square) signaled which of the two tasks the participant should perform. The instruction appeared only 150 ms prior to the target word, ensuring that necessary mental preparations to perform the task (i.e., to establish a particular dominant task set) would be incomplete when the word appeared. An unconscious prime stimulus (again a diamond or square) was also presented shortly prior to the instruction: On half the trials, this unconscious stimulus was congruent with the instruction in

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that it signaled the same task, and on the other half, it was incongruent with the instruction, signaling the other task. Responses to the word tasks were significantly faster when prime and instruction were congruent (i.e., signaled the same task) than when they were incongruent (signaled different tasks), suggesting that the unconscious prime had influenced task set selection.

One factor that arguably complicated the interpretation of Lau and Passingham's (2007) findings is that they employed unconscious primes that were the same shapes as the *conscious* task instructions. Thus, whenever the prime and instruction signaled the same task, they were the same shape, but they were different shapes when they signaled different tasks. The primes and instructions were of different sizes, minimizing priming at early stages of vision, but not at later stages that generalize spontaneously across differences in retinal size (Clifford & Rhodes, 2005). This raises three potential difficulties. First, any effects of unconscious primes in their study might have reflected not direct triggering of task set selection by unconscious stimuli but, rather, *perceptual* priming of the task instruction (Bachmann, 1989). Since unconscious primes and conscious task instructions were the same shapes, the preceding prime, although perceived unconsciously, might have enhanced the perception of the instruction on congruent trials. Enhanced perception of the task instruction alone might then have been responsible for activation of the dorsolateral prefrontal cortex (dlPFC), speeded task set selection, and shorter reaction times (RTs) observed on congruent trials; there need not have been any effects of the prime beyond perceptual priming of the instruction. Second, participants were informed consciously and explicitly of the relationship between each shape and its associated task. Accordingly, conscious knowledge of the prime–task relationships might have been necessary to observe effects of unconscious primes. Third, because the primes that might appear on a given trial were the same two shapes that the participant must actively try to detect and recognize as conscious task instructions, they would have had an active attentional set to search for those shapes; hence, the role of conscious attentional set remained uncertain. This point was raised explicitly by Leonard and Chiu (2007) in their commentary on the Lau and Passingham study.

A subsequent study (van Gaal, Ridderinkhof, Fahrenfort, Scholte, & Lamme, 2008) attempted to control for perceptual effects of the prime when unconscious stimulation of cognitive control processes was assessed. In their experimental condition, van Gaal and colleagues (2008) presented three types of trials. When a black annulus was presented alone (a *go* trial), the participant was instructed to press a response key as quickly as possible. When, however, the annulus was preceded by a consciously

perceived gray circle, they were to inhibit their response (a *conscious no-go* trial). Finally, on some trials, the gray circle was presented briefly just prior to the annulus, such that due to the overlap between the circle's outer edge and the annulus's inner edge, the circle was masked by the annulus, preventing awareness of the circle. On this third type of trials (*unconscious no-go*) trials, responses were (slightly) more likely to be inhibited relative to *go* trials, indicating that the prime had influenced inhibition processes.

In a control experiment, *go* and conscious and unconscious *no-go* trials were now presented again, but conscious *no-go* trials were altered, such that a consciously perceived *X* indicated that the response to the annulus should be inhibited. The logic was that any perceptual effects of the circle on the annulus on the unconscious *no-go* trials would be identical in the main versus control experiments but that the significance of the gray circle for response inhibition would hold only in the main experiment, where it signified a *no-go* trial, not in the control experiment. It was found that the masked gray circle in the control experiment could no longer inhibit response. Arguably, however, the main and control experiments were not comparable. RTs on *go* trials were markedly shorter (>10%) in the control than in the main experiment for all three sessions of the study. That is, the baseline from which the authors subtracted unconscious *no-go* RTs in the main experiment to index the effect of the unconscious prime differed substantially from that in the control experiment, such that assessment of the unconscious stimulus's effect was rendered ambiguous. We suspect that the RT difference between the *go* trials reflected the greater perceptual similarity of the annulus to the gray circle in the main experiment than to the cross in the control experiment, allowing participants to make their decisions in the latter experiment on the basis of less perceptual evidence.

A third, more recent study did preclude perceptual priming effects (van Gaal, Ridderinkhof, Scholte, & Lamme, 2010). van Gaal and colleagues (2010) presented four types of trials: weakly masked (conscious) *go* trials, weakly masked (conscious) *no-go* trials, strongly masked (unconscious) *go* trials, and strongly masked (unconscious) *no-go* trials. Participants were instructed to respond as quickly as possible to a white annulus but to withhold their responses when a white square briefly preceded the annulus. However, when a diamond preceded the annulus, participants were instructed to respond as quickly as possible. The annulus also acted as a metacontrast mask to the preceding shape. Shapes signaling *go* and *no-go* responses were presented for a relatively longer time duration in weakly masked conditions than in strongly masked conditions; thus, these shapes were consciously perceived in weakly masked conditions and remained

subliminal in strongly masked conditions. RTs were significantly longer on strongly masked no-go trials, relative to strongly masked go trials. This paradigm eliminated possible perceptual priming effects between the prime (a diamond or a square) and instruction (an annulus). However, in both unconscious and conscious conditions, the association between the stimulus and go or no-go response in the weakly masked trials was established consciously and verbally. Such conscious awareness of the instructional value of the prime's shape might induce an active attentional set, since participants were constantly searching for the presence of the prime shape in both the conscious and unconscious conditions (Leonard & Chiu, 2007). Accordingly, it might yet be that an unconscious stimulus can trigger task set selection only once an association between the stimulus and that function has been *consciously* established and while the participant is actively searching for the same shapes that are used as unconscious primes.

The aim of Experiment 1 was to demonstrate unconscious priming of cognitive control without the need for participants to have a conscious, explicit attentional set to search for the same shapes used as primes. To achieve this, in any given block of trials, the shapes used as unconscious primes should not be presented as conscious instructions, either on the same trial or on different trials within that block. This would (1) preclude any influence of perceptual priming between prime and instruction and (2) prevent the participant from establishing a current attentional set to search for those shapes used as unconscious primes. However, this would be possible only if prime–task associations had been established beforehand, which would allow the shapes to prime the selection of task sets (note that, as in previous studies, the unconscious stimuli would not necessarily control executive functions themselves but would prime the selection of one task set over others). Accordingly, we introduced a learning phase to the experiment, seeking to establish an association between two instruction shapes and two types of word tasks. Subsequently, in a second, test phase, two new arbitrary shapes were used as conscious instructions, while the previous instruction shapes encountered in the learning phase were presented only as unconscious primes. That is, throughout the test phase of the experiment, the shapes employed as unconscious primes were never presented as conscious task instructions, such that the participant should not have held an attentional set to search for those shapes.

In addition to these new types of trials, unique to the present experiments, we also included trials on which the prime shapes were also used as conscious instructions in the test phase, but not in the learning phase. These trial types closely paralleled the conditions employed by Lau and Passingham (2007). We included these trials so as to be

able to compare any influences of focused, spatial attention to the prime stimuli in the two cases. Previous semantic priming studies had shown that subliminal processes were modulated by temporal and spatial attention (Naccache, Blandin, & Dehaene, 2002), which suggested that priming effects by unconscious stimuli are subject to modulation by conscious top-down factors. However, as was noted by Leonard and Chiu (2007), neither of the previous studies above explicitly manipulated attention, subsuming this under the heading “conscious attention,” which they manipulated by masking alone. Thus, the modulation of unconscious priming of cognitive control by spatial attention remained unclear. To manipulate spatial attention to the prime stimuli in Experiment 1, we presented a central arrow cue (pointing left or right) prior to presentation of the unconscious prime, which instructed participants to attend to one of two possible prime locations. To ensure that participants complied with this instruction, a small red or green dot appeared on the cued side only, signaling that the participant should either perform the task as usual (following a green circle) or exit the trial by pressing the space bar (following a red circle). The logic of this manipulation was that only by attending to the location indicated by the arrow cue could the participants accurately determine the circle's color and incorporate this into their response.

Experiments 1A and 1B

Two versions of the experiment were conducted (on separate groups of participants. In Experiment 1A, the prime and instruction were always of different shapes. Half of the trials in Experiment 1B were as for Experiment 1A. The remaining trials were designed to parallel, in several key respects, the conditions in Lau and Passingham's (2007) study; the unconscious prime stimuli (not encountered in the experiment's learning phase) were the same shapes as the conscious instructions used in the test phase and were associated with a task only via their physical similarity to the conscious instructions.

Method

Participants Sixteen paid participants were recruited in Experiment 1A (5 of them male, 11 female; 18–34 years of age) and 24 in 1B (6 of them male, 18 female; 18–31 years of age).

Stimuli, apparatus, and procedure The experiment was conducted on an eMac monitor with a refresh rate of 112 Hz. Stimuli were presented in black on a white background. Figure 1 schematizes a typical trial's display

Fig. 1 Schematization of a typical trial's display sequence in test phases of Experiments 1A and 1B. Note that only the prime display (third from top in figure) distinguished the learning from the test phase, being a white blank screen in the learning phase but comprising an unconscious prime shape in the test phase

sequence in the learning and test phases in Experiments 1A and 1B. The learning phase was intended to ensure that participants associated one of the two instruction shapes (a hexagon, circle, square, or diamond, counterbalanced across participants) with each of the two tasks. On each trial, following a fixation cross, a centrally presented arrow cue (100 ms) instructed participants to shift their attention to the left or right. Following a brief blank screen, two compound masks (50 ms; subtending 2° of retinal angle vertically and horizontally) were presented left and right, with a small colored dot at the center of each (their illustrated size in Fig. 1 is doubled horizontally and vertically relative to other elements, to aid visibility). On the attended side (i.e., the side pointed to by the arrow), the small dot was colored either green or red, whereas the dot on the unattended side was half green half red (so as to minimize any differences between cued and uncued sides in terms of the masking or cuing effects of the dots themselves). Participants were instructed to press the “Stop” key (zero on the keypad) if the dot on the attended side was red; this action terminated the trial. Alternatively, if the dot was green, participants were required not to respond to the dot but simply to perform one of the two word tasks as indicated by the instruction. The instruction (a hexagon or circle; 50 ms; subtending 1.9° of retinal angle vertically and horizontally) was displayed just before the presentation of the target word, signaling which of two tasks (semantic or phonological) the participant should perform on the subsequent target word; both instruction and

word appeared at fixation. On the semantic task, participants judged whether the target word referred to a concrete object or not and, in the phonological task, whether the word had two syllables or not (i.e., bisyllabic), pressing one of two response keys as quickly as possible to indicate their decision.

The target words used in the experiment were selected from the Medical Research Council Psycholinguistic Database (Wilson, 1988). Words used in the semantic task were selected with the criteria >550 (concrete) and <350 (abstract) on the concreteness scale. In the phonological task, words containing two syllables according to the database were considered as bisyllabic, and words with one or three syllables were selected from the database as nonbisyllabic. The words were systematically counterbalanced so that words presented on half of the trials in each condition required the same motor response in both the phonological and the semantic tasks.

In the test phase, which was identical in all other respects to the learning phase, the two shapes that had been employed as instructions in the learning phase were used as unconscious primes (9 ms), presented just prior to the compound masks (50 ms). On each trial, a prime was displayed 9° to the left or right of the fixation such that the compound mask's edges overlapped with each prime's (i.e., each of the four possible prime shapes') edges. The primes appeared with equal frequency on the attended or unattended side.

Two of the four shapes (diamond, square, circle, hexagon) that had not been employed for a given

participant during the learning phase now served as conscious task instructions in the test phase. Combinations of prime shape, instruction shape, and task were fully counterbalanced across participants, precluding systematic perceptual priming between the prime and instruction. On half of the trials in Experiment 1A's test phase, the prime was congruent with (signaled the same task as) the instruction, and on half, it was incongruent (signaled the other task). Note that on both congruent and incongruent trials, the prime and instruction were always of entirely different shapes.

In the test phase of Experiment 1B, half of the trials had the same form as in Experiment 1A. For brevity, we term these *Z&D* (Zhou & Davis) trials to denote that they were associated with individual word tasks due to presentation during the learning phase and were always different from the shapes used as instructions during the test phase. These trials differed in two key respects from the remaining trials, which were designed to mimic conditions employed by Lau and Passingham (2007) in that two unconscious prime shapes in the test phase were the same as those employed as conscious instructions in the test phase and derived their association with a task only by virtue of their similarity to the conscious task instructions, which in turn were associated with the task via explicit verbal instruction. The latter trials we term *L&P* trials, since they paralleled in these key respects the procedure employed by Lau and Passingham. On congruent L&P trials, prime and instruction were the same shape signaling the same task, and on Incongruent L&P trials, different shapes signaling different tasks. L&P and Z&D trials were randomly intermixed throughout the testing phase of Experiment 1B.

The learning and test phases of each experiment consisted of three blocks of 64 trials (following 32 practice trials each). Conscious awareness of the prime's identity was assessed using a forced choice discrimination task (two blocks of 64 trials) following the test phase. The same stimulus sequences were presented as for the main task, except that following the compound masks, instead of presenting a task instruction shape to signal one of the two word tasks, an instruction, ("Which shape did you see?") was presented to signal the discrimination task. Participants attempted to identify the masked prime's shape on each trial, by pressing one of two keys (Experiment 1A) or of four keys (Experiment 1B) accordingly. Selection of this awareness criterion reflected growing consensus in the research literature on unconscious perception that awareness tests should (1) assess consciousness of the same information that is claimed to arise unconsciously (in our case, the primes' identities, not their presence/absence) and minimize memory/dual-task constraints in the awareness test, re-

ducing the potential for consciously perceived stimuli that are not established as memory traces to be characterized as unconscious, and (2) be sensitive to all of the relevant conscious knowledge (Shanks & St. John, 1994).

In one respect, this criterion for awareness was arguably less conservative than those in some previous studies in that it concerned awareness of the prime's identity, rather than its presence. However, since it best satisfies the guidelines provided by previous work, its benefits seem to outweigh this potential cost.

Results and discussion

Data from 4 participants in Experiment 1B who scored less than 70% correct responses were excluded from analysis. The remaining participants responded accurately to the red or green dot (average, 98.5%), indicating that they had performed this part of the task as instructed. Participants' accuracy in discriminating the primes' identities did not differ from chance in either experiment, as estimated for bias-free participants using d' (Macmillan & Creelman, 1991; Reingold & Merikle, 1988). For m -AFC designs, discriminability is calculated as a function of accuracy and m (Green & Dai, 1991; Stanislaw & Todorov, 1999). The average discriminability was 0.04 (SD 0.20) in Experiment 1A and 0.07 (SD 0.18) in Experiment 1B, which did not differ significantly from zero [1A, $t(15) = -0.76$, $p = .46$; 1B, $t(19) = 1.64$, $p = .12$]. Participants' performance in attended and unattended conditions in the discrimination task of the primes was also analyzed. In Experiment 1A, the average performance was 0.09 (SD 0.20) in the attended condition and 0.02 (SD 0.34) in the unattended condition. They did not differ significantly from zero [attended, $t(15) = -1.97$, $p = .07$; unattended, $t(15) = -0.26$, $p = .80$] or from each other, $t(15) = -1.27$, $p = .22$; note that any tendency for an effect in the cued condition reflected the potential for performance to dip below chance, rather than above, and was not replicated in any of the other three experiments here. Similar results were obtained from Experiment 1B; the average performance was 0.12 (SD 0.34) in the attended condition and 0.04 (SD 0.27) in the unattended condition. They did not differ significantly from zero [attended, $t(19) = 1.50$, $p = .15$; unattended, $t(19) = -0.63$, $p = .54$] or from each other, $t(19) = 1.42$, $p = .17$. Only the analysis of correct RTs in the test phase is detailed here; analyses of error rates identical to those reported below yielded no significant main effects or interactions that might threaten that analysis (1A, all F s < 1.78, n.s.; 1B, all F s < 1.01, n.s.).

Figure 2a plots RTs for conditions from Experiment 1A; note that in both the attended and unattended prime conditions, congruent trials (i.e., where prime and instruc-

Fig. 2 Reaction times (RT's) (% errors; error bars, 1 *SEM*) for Experiment 1A (a) and Experiment 1B (b) following primes at attended (cued) versus unattended (uncued) locations, which were congruent or incongruent with the conscious instruction

tion signaled the same task) yielded faster responses than did incongruent trials. A two-way, repeated measures ANOVA with factors of prime–instruction congruence (hereafter, *congruence*; congruent, incongruent) and attention (attended, unattended) yielded a significant main effect of congruence, $F(1, 15) = 8.64$, $p = .010$, $\eta_p^2 = .37$, a marginal main effect of attention, $F(1, 15) = 4.07$, $p = .062$, and no interaction, $F(1, 15) < 1$, n.s.. That is, attention did not influence the effect of the prime (congruence), exhibiting only a nonsignificant trend to affect overall RTs.

Figure 2b (right-hand side) plots the trials in Experiment 1B that replicated the conditions in Experiment 1A (i.e., Z&D trials). Visual inspection of the plot suggested that the same effects had arisen in this second experiment. In contrast, visual inspection of the results for corresponding L&P conditions, plotted on the left side of Fig. 2b, suggested that a congruence effect had arisen

only for primes presented at attended locations. A three-way, repeated measures ANOVA with factors of trial type (L&P, Z&D), prime–instruction congruence, and attention for RTs in Experiment 1B yielded no effect of trial type, $F(1, 19) < 1$, n.s., a significant main effect of congruence, $F(1, 19) = 16.2$, $p = .001$, $\eta_p^2 = .46$, no effect of attention, $F(1, 19) < 1$, n.s., but crucially, a significant three-way interaction between them, $F(1, 19) = 5.18$, $p = .035$, $\eta_p^2 = .21$.

This three-way interaction reflected markedly different influences of attention on the congruence effects in Z&D versus L&P trials. In the Z&D trials, a two-way within-participants ANOVA yielded a main effect of congruence, $F(1, 19) = 10.9$, $p = .004$, $\eta_p^2 = 0.37$, no main effect of attention, $F(1, 19) < 1$, n.s., and no interaction, $F(1, 19) < 1$, n.s.. Again, attention had not influenced the effect of the prime (congruence) and, on this occasion, not even overall RTs. An identical analysis of L&P trials yielded a main effect of congruence, $F(1, 19) = 5.69$, $p = .028$, $\eta_p^2 = .23$, no main effect of attention, $F(1, 19) < 1$, n.s., but importantly, a significant interaction, $F(1, 19) = 7.65$, $p = .012$, $\eta_p^2 = .29$. This interaction reflected a significant effect of congruence in the attended condition, $t(19) = 4.06$, $p < .001$, but not in the unattended conditions, $t(19) < 1$, n.s..

Together, the results of Experiment 1A and the Z&D trials in Experiment 1B demonstrated that unconscious primes could influence task set selection processes even when the specific shapes used as primes on those trials were not currently being used as task instructions and the participant should, therefore, have no current attentional set to search for the primes' specific shapes. Moreover, this effect arose irrespective of our manipulation of spatial attention. This cannot have reflected ineffective manipulation of spatial attention, since the same manipulation did significantly affect performance on L&P trials of Experiment 1B. Instead, this result provides an initial answer to the question raised by Leonard and Chiu (2007) regarding the possible role of attention in the Lau and Passingham (2007) study, suggesting that their effects would have been minimized if participants had not attended to the unconscious prime's location.

For our primary purposes here (to assess whether unconscious stimuli can activate task set independently of spatial attention to the prime and current attentional set), it is not necessary to identify the cause of the different attention effects observed for the Z&D trials, relative to the L&P trials. Indeed, the L&P and Z&D trials (necessarily) differed in two primary respects, so the source of those different effects of attention in the two types of trials remains unclear. However, one possibility could be that on L&P trials only, the prime and instruction were of the same shape when congruent and were different shapes when incongruent, suggesting that the prime–instruction congruence effect in L&P trials might have reflected perceptual

priming between the prime and instruction. That such perceptual effects arose preferentially for attended versus unattended primes parallels findings for unconscious *perceptual* influences reported elsewhere (Posner & Petersen, 1990), which is consistent with a role for perceptual priming on those trials. Such perceptual priming was explicitly excluded in the Z&D trials. Alternatively, the different effects of attention might have reflected the different ways in which associations between prime shapes and tasks were established. For L&P trials, participants had formed no association between the prime shapes and tasks in the learning phase, and these associations were formed only in the test phase via the primes' physical similarity to the instruction shapes that were associated with tasks via verbal instructions. In contrast, the primes employed in the Z&D trials had become associated with tasks via simple pairing of task and stimulus in the learning phase and were not associated with tasks via their resemblance to conscious instructions or via verbal instruction. It is possible, therefore, that the greater directness and simplicity of the latter learning was responsible for the Z&D prime effect's independence of focused spatial attention, an issue we revisit in the [General Discussion](#) section.

One limitation of Experiments 1A and 1B (and indeed of previous studies) is that although the unconscious prime stimuli were unconsciously processed at the time of the test phase, they had been used as explicit, conscious task instructions in the previous learning phase. Therefore, consciousness of an association between prime shape and task might have been carried over to the present test phase from the previous learning phase in which primes acted as conscious instructions to the tasks. To address this issue, Experiments 2A and 2B replicated the conditions in Experiments 1A and 1B, respectively, but introduced a new variation of the learning phase in Experiment 1 to establish associations between prime shapes and tasks *unconsciously*.

Experiments 2A and 2B

Method

Participants Sixteen new participants were recruited for Experiment 2A (4 of them male, 12 female; 21–25 years of age) and 16 for Experiment 2B (3 of them male, 13 female; 21–30 years of age).

Stimuli, apparatus, and procedure Figure 3 illustrates a typical sequence of displays in the learning and test phases of Experiments 2A and 2B. The test phases in these two experiments were identical to those in Experiments 1A and 1B, respectively, but the learning phases were altered as follows. In the learning phases in Experiments 1A and 1B,

we established an association between two shapes and the two tasks by presenting one of the shapes on each trial as a conscious instruction to perform one task or the other; these shapes were then used as primes in the test phase. However, in the learning phase of Experiments 2A and 2B, no shapes were presented as conscious instructions. Rather, one of the shapes was presented unconsciously (briefly presented and masked) prior to the conscious instruction on each trial, which was either a high- (1047 Hz) or a low- (130 Hz) pitched tone (to minimize perceptual interference or priming between shapes and instructions). Although the unconsciously presented shapes were not instructions, the presentation of a particular shape predicted 100% of the time the task that participants would subsequently have to perform. This predictive relationship was intended to establish an association between each unconsciously presented shape and a corresponding task. As in Experiments 1A and 1B, the unconscious shape was no longer predictive of which task would be performed in the test phases of Experiments 2A and 2B.

Results and discussion

One participant's data in Experiment 2B, whose accuracy was lower than 70%, were excluded from analysis. Again, the remaining participants responded accurately to the red or green dot (average, 98.5%), which indicated that they had performed this part of the task as instructed. Prime identity discrimination across participants did not differ from chance in either experiment, as measured by the bias-free measure d' (Green & Dai, 1991; Macmillan & Creelman, 1991; Reingold & Merikle, 1988; Stanislaw & Todorov, 1999). The average performance was 0.01 (SD 0.19) in Experiment 2A and 0.02 (SD 0.19) in Experiment 2B. These are not significantly larger than zero [2A, $t(15) = -0.21$, $p = .83$; 2B, $t(14) = -0.86$, $p = .41$]. The average performance was also analyzed separately for attended (2A, 0.05 [SD 0.26]; 2B, 0.03 [SD 0.26]) and unattended (2A, 0.07 [SD 0.30]; 2B, 0.03 [SD 0.31]) conditions. They did not differ significantly from zero in Experiment 2A [attended, $t(15) = 0.76$, $p = .46$; unattended, $t(15) = -0.92$, $p = .37$] or in Experiment 2B [attended, $t(14) = -0.88$, $p = .40$; unattended, $t(14) = -0.61$, $p = .55$]. Also, in both experiments, performance in the attended and unattended conditions did not differ significantly from each other [2A, $t(15) = 1.18$, $p = .26$; 2B, $t(14) = -0.082$, $p = .94$]. Again, only RTs for test phase performance are presented here; analyses of error rates identical to those reported below yielded no significant main effects or interactions that might threaten the analysis of the RTs (2A, all F s < 1.18; 2B, all F s < 1).

Fig. 3 Schematization of a typical trial's display sequence in test phases of Experiments 2A and 2B. Note that only the instruction display (third from bottom in figure) distinguished the learning from the test phase, being a white blank screen accompanied by a low or high tone in the learning phase and an instruction shape in the test phase

Figure 4a plots RTs for the conditions in Experiment 2A (same format as Fig. 2a). Visual inspection of the plot suggested that influences of the unconscious primes on RTs were as for Experiment 1A, arising independently of our attention manipulation. A two-way ANOVA on the RTs yielded a significant main effect of congruence, $F(1, 15) = 9.15$, $p = .009$, $\eta_p^2 = .38$, no main effect of attention, $F(1, 15) < 1$, n.s., and no interaction between the two, $F(1, 15) < 1$, n.s. The effect of congruence was not significantly influenced by attention.

RTs from Z&D trials of Experiment 2B (plotted in Fig. 4b, same format as in Fig. 2b) again showed the same pattern as that for the corresponding trials in Experiment 2A. However, as for Experiment 1B, results from the L&P trials appear, on visual inspection of Fig. 4b, to show reliable congruence effects only for attended primes, consistent with a significant enhancement of those effects by visual attention to the prime's location. A three-way repeated measures ANOVA identical to that performed for Experiment 1B yielded no main effect of congruence, $F(1, 14) = 3.39$, $p = .09$, no effect of attention, $F(1, 14) = 3.64$, $p = .077$, and no effect of trial type, $F(1, 14) = 1.79$, n.s., but a significant three-way interaction between these three factors, $F(1, 14) = 16.4$, $p = .001$, $\eta_p^2 = .54$.

As for Experiment 1B, this three-way interaction reflected markedly different influences of attention on the congruence effects on Z&D versus L&P trials. For Z&D trials, an ANOVA identical to that performed in Experiment 2A yielded a main effect of congruence, $F(1, 14) = 5.27$, $p = .038$, $\eta_p^2 = .27$, no main effect of attention, $F(1, 14) = 1.99$, $p = .18$, and no

interaction between the two, $F(1, 14) = 3.17$, $p = .097$; this nonsignificant trend toward an interaction reflected a numerical tendency for larger effects with unattended primes. An identical ANOVA conducted for L&P trials yielded no main effects of congruence, $F(1, 14) < 1$, n.s., or attention, $F(1, 14) < 1$, n.s., but an interaction between the two, $F(1, 14) = 7.10$, $p = .018$, $\eta_p^2 = .34$. This interaction reflected a significant congruence effect for attended, $t(14) = 2.54$, $p = .023$, but not unattended, $t(14) = 1.28$, n.s., trials, paralleling the effects seen for L&P trials in Experiment 1B.

The results of Experiments 2A and 2B indicated that the primes, *unconsciously* associated with tasks, influenced task set selection. That is, unconscious priming of cognitive control did not require conscious or explicit associations between the primes and respective tasks to be formed but, rather, could proceed via unconscious association. Again, for Z&D trials, such influences were not modulated significantly by attention, and any (nonsignificant) trend was toward greater congruence effects for primes at *unattended* locations. L&P trials, however, in which the prime shapes had no association with the task other than via their similarity to the conscious instructions, showed congruence effects only for primes that appeared at attended locations.

General discussion

In previous studies of unconscious activation of task set selection and inhibitory executive mechanisms, participants

Fig. 4 Reaction times (RT's) (% errors; error bars, 1 SEM) for Experiment 2A (a) and Experiment 2B (b) following primes at attended (cued) versus unattended (uncued) locations, which were congruent or incongruent with the conscious instruction

were always actively anticipating or even searching for the shapes used as prime stimuli and consciously associating them with a task when the unconscious primes were presented. Such an active attentional set, as was argued by Leonard and Chiu (2007), might be necessary for unconscious control to take place. The present experiments, however, provided evidence for unconscious activation of cognitive control mechanisms of task selection, even when an active attentional set for unconscious stimuli was eliminated.

The role of focused spatial attention to an unconscious prime's location under these novel conditions was compared with the role of attention in conditions similar to those used by Lau and Passingham (2007). This comparison was fortuitous, since only in our new procedure, using entirely differently-shaped primes and instructions, was apparent independence of such effects from spatial attention observed. Indeed, using our procedure highlighted elements of unconscious control activation that were, if anything, more reliable for primes

appearing at unattended than at attended locations (although no greater in magnitude). In contrast, conditions that closely paralleled those in Lau and Passingham's study showed the classic pattern of attentional mediation, arising preferentially for attended primes. The significant mediation of the latter conditions by attention argues strongly for the efficacy of our attention manipulation, indicating that the independence of unconscious influences in our own new types of trial could not be ascribed to an ineffective attention manipulation.

One potential source of the very distinct influences of attention on our L&P trials versus Z&D trials is perceptual priming (between representations of the prime and instruction) in the L&P congruent trials only. That such perceptual priming might be enhanced by attention is consistent with findings regarding unconscious influences on semantic, perceptual, motor, and exogenous-cuing processes reported elsewhere (Ansorge, Horstmann, & Worschech, 2010; Finkbeiner & Palermo, 2009; Kiefer & Brendel, 2006; Liu, Pestilli, & Carrasco, 2005; Marzouki, Grainger, & Theeuwes, 2007; Sumner et al., 2006; Van den Bussche, Hughes, Van Humbeeck, & Reynvoet, 2010). Alternatively (or in combination with the above), the origin of these findings might lie in the different ways that participants learned the stimulus–task associations on our Z&D trials (trial-by-trial temporal contiguity of stimulus and performance of the task) versus our L&P trials and other studies (explicit instructions). It might be that explicit relations between prime shapes and tasks, as in the case of L&P trials, might imply an active attentional set for prime shapes while participants were constantly identifying instruction shapes, and such an active attentional set might enhance the effects of spatial attention. On the other hand, it might be that only those more phylogenetically ancient learning mechanisms required to form the requisite associations on our Z&D trials are simply triggered more independently of attention.

Although the explanation for different effects of attention is beyond the scope of this article, this does not detract from our two major contentions. The first of these is that unconscious stimuli can influence task selection even when no explicit association between task and stimulus is formed and, indeed (in Experiment 2), when the stimuli responsible for the effect cannot be consciously identified during either the learning or test phase. The second is that such effects (on our Z&D trials) appear to arise relatively independently of focused spatial attention.

An attractive physiological speculation concerning how unconscious stimuli can activate task selection relatively independently of attention concerns dorsal-LGN magnocells' putative rapid activation of prefrontal regions (Bar, 2003; Bar & Aminoff, 2003) involved in task selection. It seems plausible that among these regions, the (dl)PFC may drive task set selection on the basis of visual information that bypasses many extrastriate sites of selective attention, such

that those processes operate relatively independently of spatial attention. However, if such *attention independent* routes are indeed exploited, this appears to arise only when prime stimuli are associated with tasks using simple temporal contiguity (as in our Z&D trials). When, instead, unconscious stimuli are associated with tasks only by verbal instructions (as in all previous work on this topic and on our L&P trials), no effects appear to arise for primes at unattended locations, presumably reflecting substantial gating of those stimulus effects by visual attention in the extrastriate cortex.

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